Large-Scale Energy Center in Michigan:

Energy Storage and Distributed Energy Generation Project

Transportation Energy Center (TEC), *University of Michigan, Ann Arbor*

DoE Visualization and Controls

Peer Review

Oct.17-18, 2006

Arlington, Virginia

Presenter:

Johannes Schwank
Professor of Chemical Engineering and Director TEC

University of Michigan

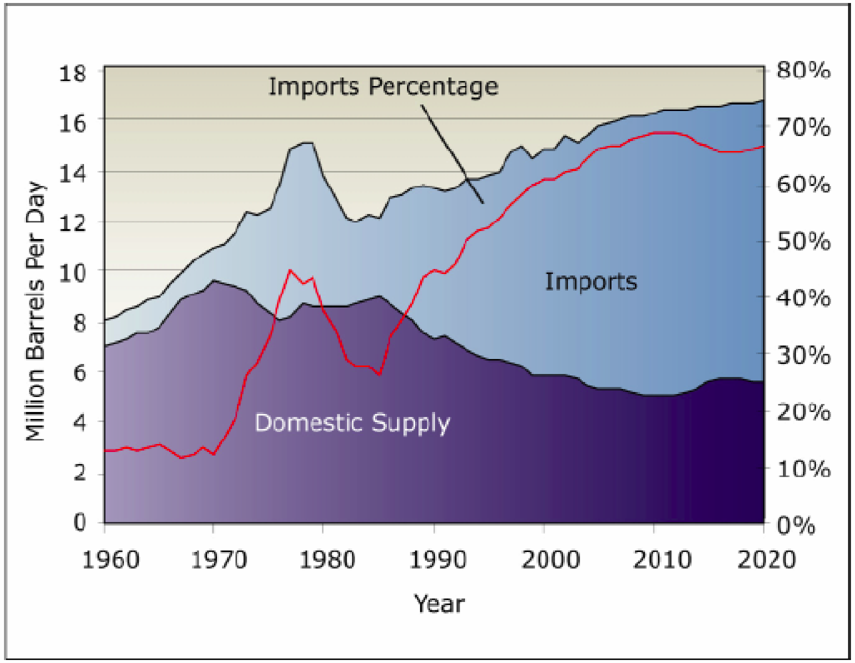
- Established in 1817
- 25,467 undergraduate students
- 14,219 graduate students
- 2,787 faculty; 618 research scientists, 12,762 staff
- 538 major buildings on 3,075 acres
- Nineteen schools and colleges
  - Top rated schools in engineering, business, information, law, medicine, public health, social work, psychology…
- 3 hospitals
- Annual research expenditures of $778 million
- 7.6 million volumes in 19 libraries

University of Michigan College of Engineering

- Established in 1854, the seventh oldest school of engineering in the U.S.
  - 11 Departments
  - 23 Degree Programs
- With 4,943 undergraduate and 2,579 graduate students, one of the largest and most comprehensive programs in the country.
- 306 faculty; 79 research scientists, 513 support staff
- Total budget ~ $ 295 million
- Annual research expenditures of $132 million
- A continuing education distance learning program which has reached more than 54,000 engineers and scientists

Overview of Transportation Energy Center Research

Problem: Reliance on imported oil



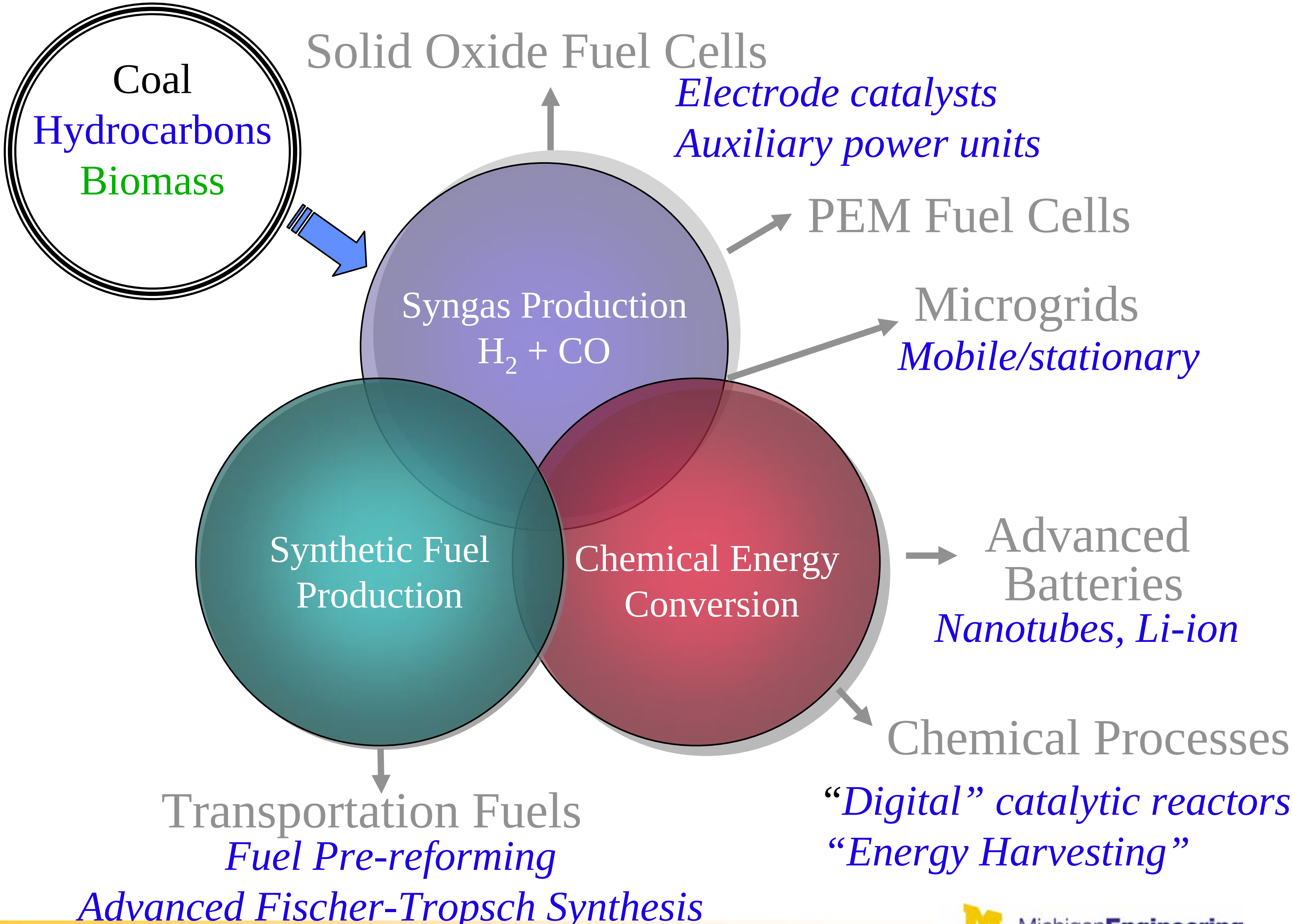
Source: EIA

Vision

Numerous, advanced fuel options that transition our Nation to energy independence

- *creating clean-burning synthetic fuels*
- *harvesting energy while producing value-added chemicals*
- *exploring the interface between mobile and stationary energy conversion systems*

TEC Research Portfolio



Project Description

Energy Storage and Distributed Energy Generation

- Objective:
  - Contribute solutions to major fundamental research and technology challenges for securing a reliable and sustainable electric power supply for the Nation
- Research themes:
  - Advanced Energy Storage
  - Alternative Energy Sources
  - Control of Power Systems
- Timing
  - Initiated June 2006
  - One year effort

Interdisciplinary Research Team
Energy Storage and Distributed Energy Generation

- **Advanced Energy Storage**
  - Advanced materials for battery applications
    - Ann Marie Sastry (Mechanical Engineering)
    - Levi Thompson (Chemical Engineering/HETL)
    - Jerry Mader (Chemical Engineering)
- **Alternative Energy Sources**
  - PEM fuel cells
    - Anna Stefanopoulou (Mechanical Engineering)
    - Levi Thompson (Chemical Engineering)
  - Solid Oxide Fuel Cells
    - Suljo Linic (Chemical Engineering)
    - Johannes Schwank (Chemical Engineering)
  - Compact fuel processors
    - Levi Thompson (Chemical Engineering/HETL)
    - Johannes Schwank (Chemical Engineering)
  - Non-combustion based chemical energy sources
    - Johannes Schwank (Chemical Engineering)
    - Xiaoyin Chen (Chemical Engineering)
- **Control of Power Systems**
  - Power and Information Management
    - Anna Stefanopoulou (Mechanical Engineering)
  - Power Electronics
    - Chunting (Chris) Mi (Electrical and Computer Engineering)
    - Keshav Varde (Mechanical Engineering)

Project Tasks

1. Create advisory board ✔
2. Review of plans, objectives, and programs of DoE Office of Electricity Delivery and Reliability (OEDER) ✔
3. **Identify opportunities for development of new enabling technologies**
4. Select and initiate specific long-term research projects
5. Develop partnering opportunities designated by DoE

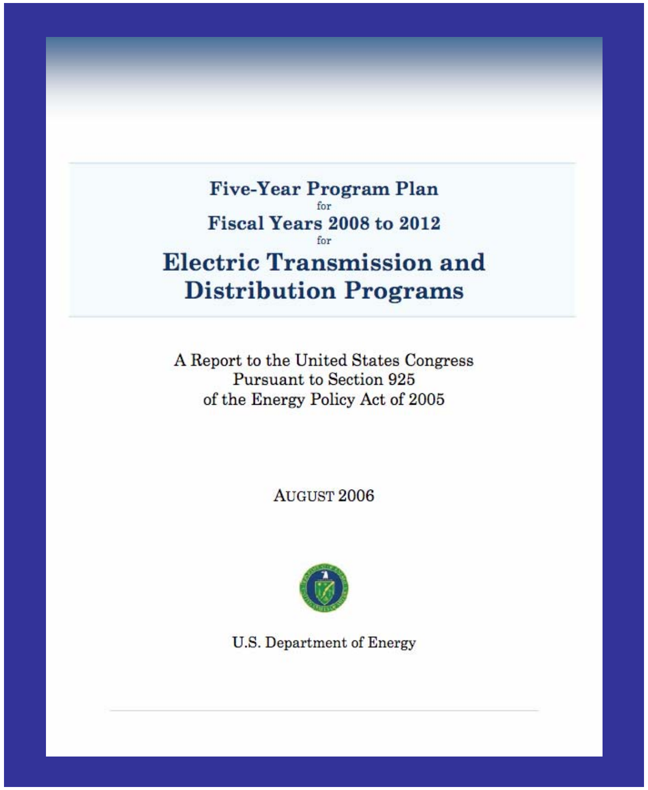
Task 1

Create advisory board

- Defined advisory board role as
  - Provide input and advice in the selection of relevant and promising research projects for improving electrical grid security and reliability
  - Facilitate connectivity with existing research and technology demonstration efforts in Michigan
  - Engage industry via industrial working group (membership in thesis committees, participation in workshops, site visits, interviews, etc.)
- Identified members of industrial working group
  - GM - Ahsan Habib
  - Ford - Ted Miller
  - Ford - Anand Sankaran
  - National Automotive Center - Erik Kallio
  - Next Energy - Jim Groce

Task 2
Office of Electricity Delivery and Energy Reliability - Program Plan Review

- "Grid 2030" A National Vision for Electricity's Second 100 Years, July 2003
- Electric Distribution, Multi-Year Research, Development, Demonstration and Deployment Technology Roadmap Plan: 2005-2009, December 2004
- Overview of the Office of Electricity Delivery and Energy Reliability, May 25, 2006
- Five-Year Program Plan for FY2008 to FY2012 for Electric Transmission and Distribution Programs, August 2006



New Five-Year Program Plan for Electric Transmission and Distribution Programs

- Five-year Program Plan relevance to DOE-UM Energy Storage and Distributed Generation Project
  - 3.0 Transmission and Distribution Planning and Operation Technology
  - – 4.0 High Temperature Superconductivity
  - 5.0 Distributed Systems Integration
  - 6.0 Power Electronics and Enabling Materials
  - – 7.0 High Voltage Transmission
  - – 8.0 High Power Density Industry Applications

Task 3
Opportunities for development of new enabling technologies

5.0 Distributed Systems Integration

"Advanced operational strategies such as local energy networks…for example microgrids… integrated power delivery system consisting of interconnected loads and distributed energy systems."

Five-Year Program Plan for FY2008 to FY2012 for Electric Transmission and Distribution Programs, August 2006, p. 38

- UM Project to investigate novel distributed energy options where electricity is a by-product of chemical processes, i.e., energy harvesting
- UM Project to develop control strategies for microgrid and distributed power that integrate advanced energy storages and sources

Inventory of potential distributed energy resources in Michigan

Biomass

Studies indicate that Michigan has good biomass resource potential.

Geothermal

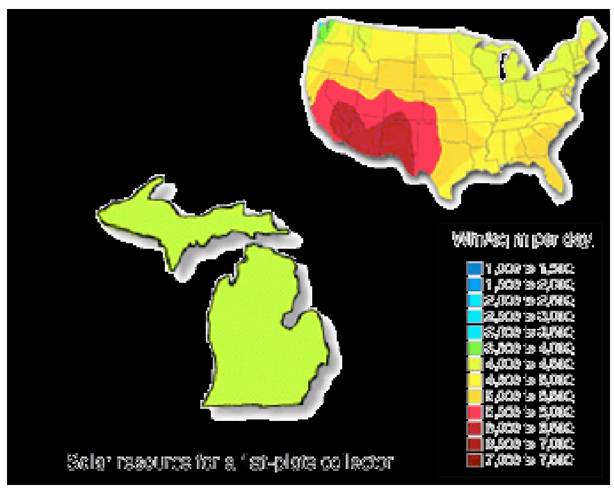
Michigan has vast low-temperature resources suitable for geothermal heat pumps. However, Michigan does not have sufficient resources to use the other geothermal technologies.

Hydropower

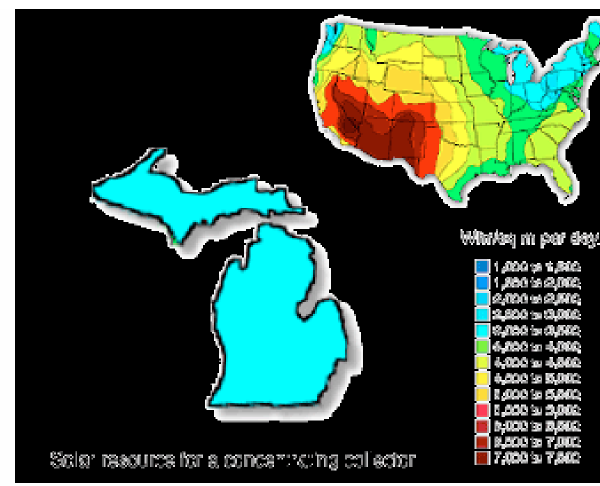
Michigan has a relatively low hydropower resource as a percentage of the state's electricity generation.

Solar

For flat-plate (static) collectors, Michigan has a useful resource throughout the state. For concentrating collectors (which follow the sun), Michigan has a relatively poor resource.



Solar resource, flat plate collector

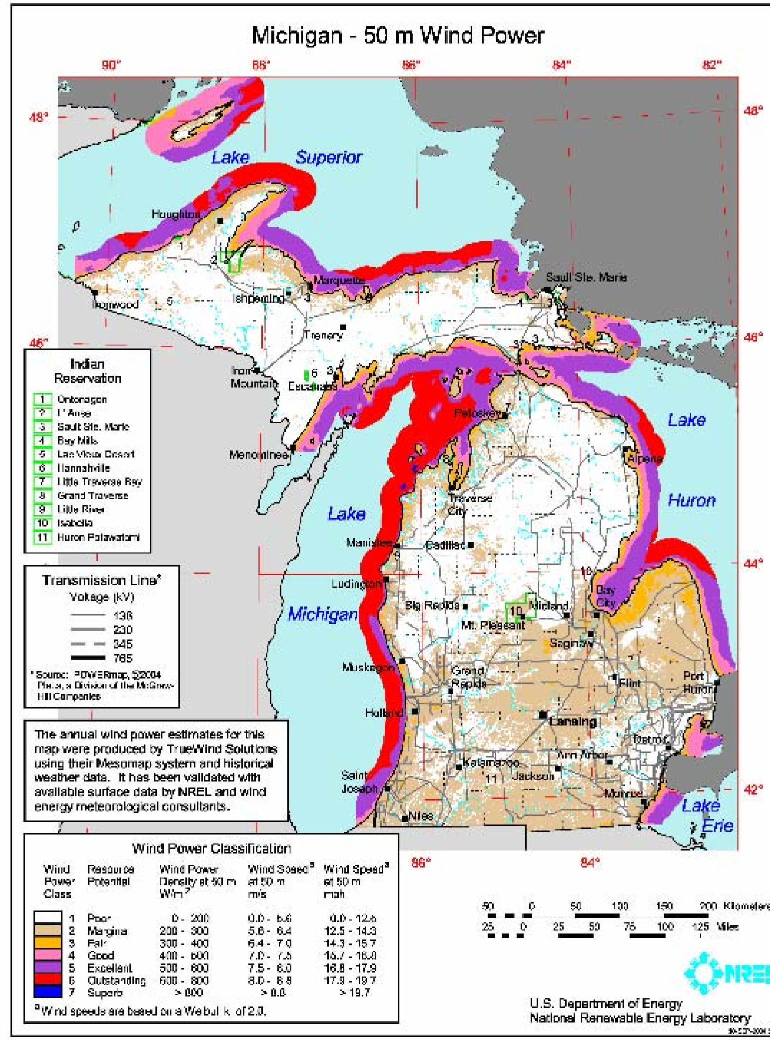


Solar resource, concentrating collector

Inventory of Energy Resources in Michigan, cont'd

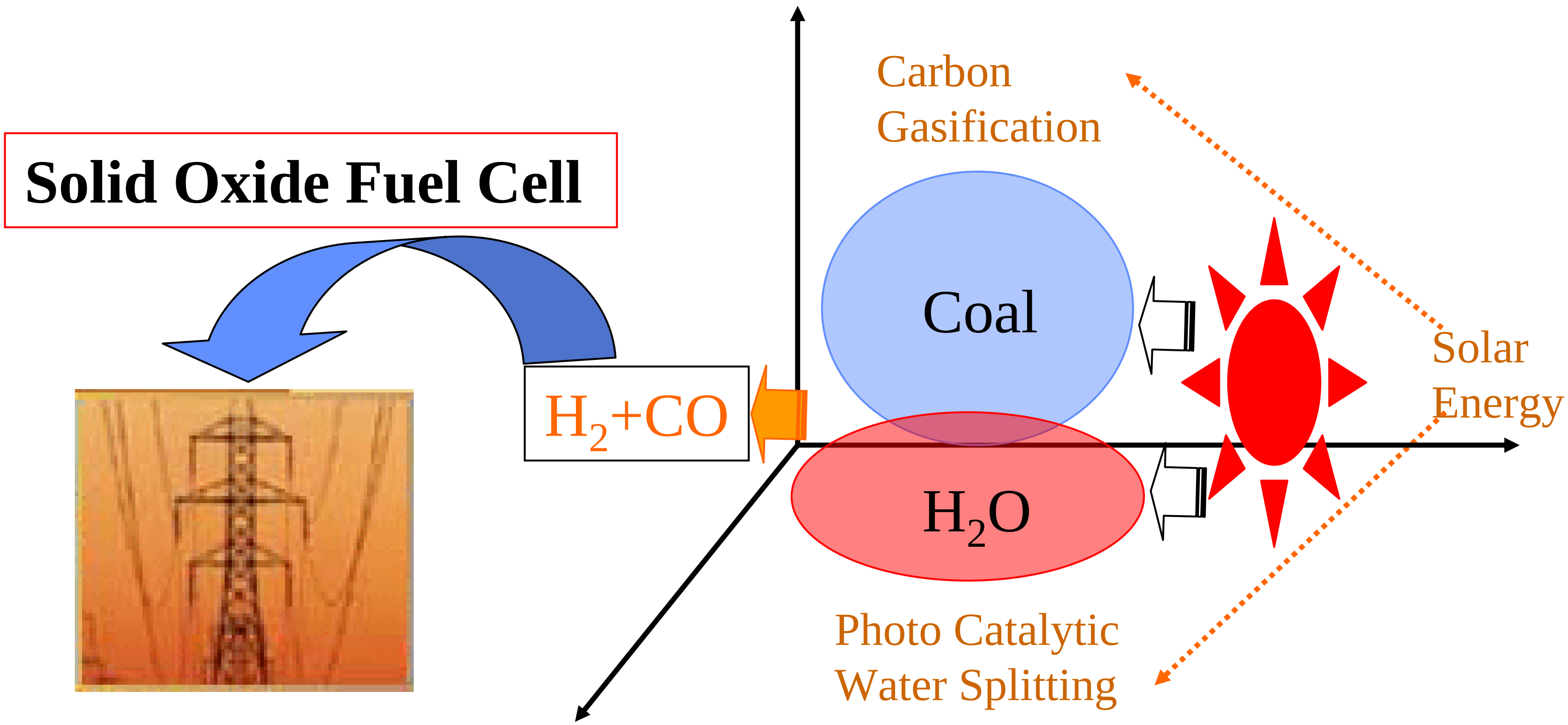
Wind

Michigan has wind resources consistent with utility-scale production. The map shows that the onshore utility-scale wind resources in Michigan are concentrated along the immediate shores of the Great Lakes (especially Lakes Michigan and Superior) and on offshore islands. The Great Lakes have good to outstanding wind resource. In addition, small wind turbines may have applications in some areas.



Energy Harvesting Concept:

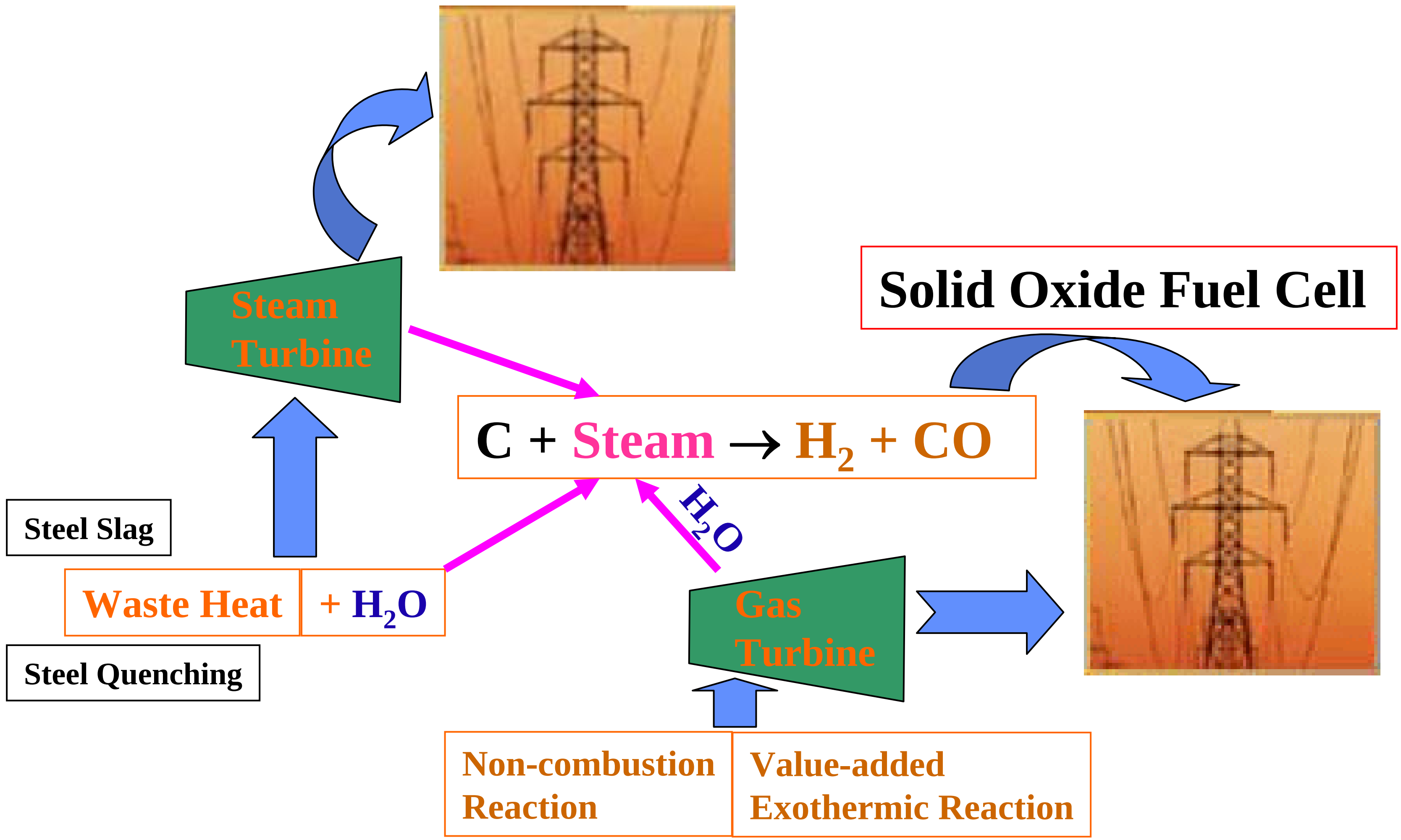
Combination of Solar Energy and Water to Assist Coal Gasification



$$C + H_2O + h\nu \rightarrow H_2 + CO$$

Energy Harvesting Concept:

Combination of Waste Heat Recovery and Syn-gas

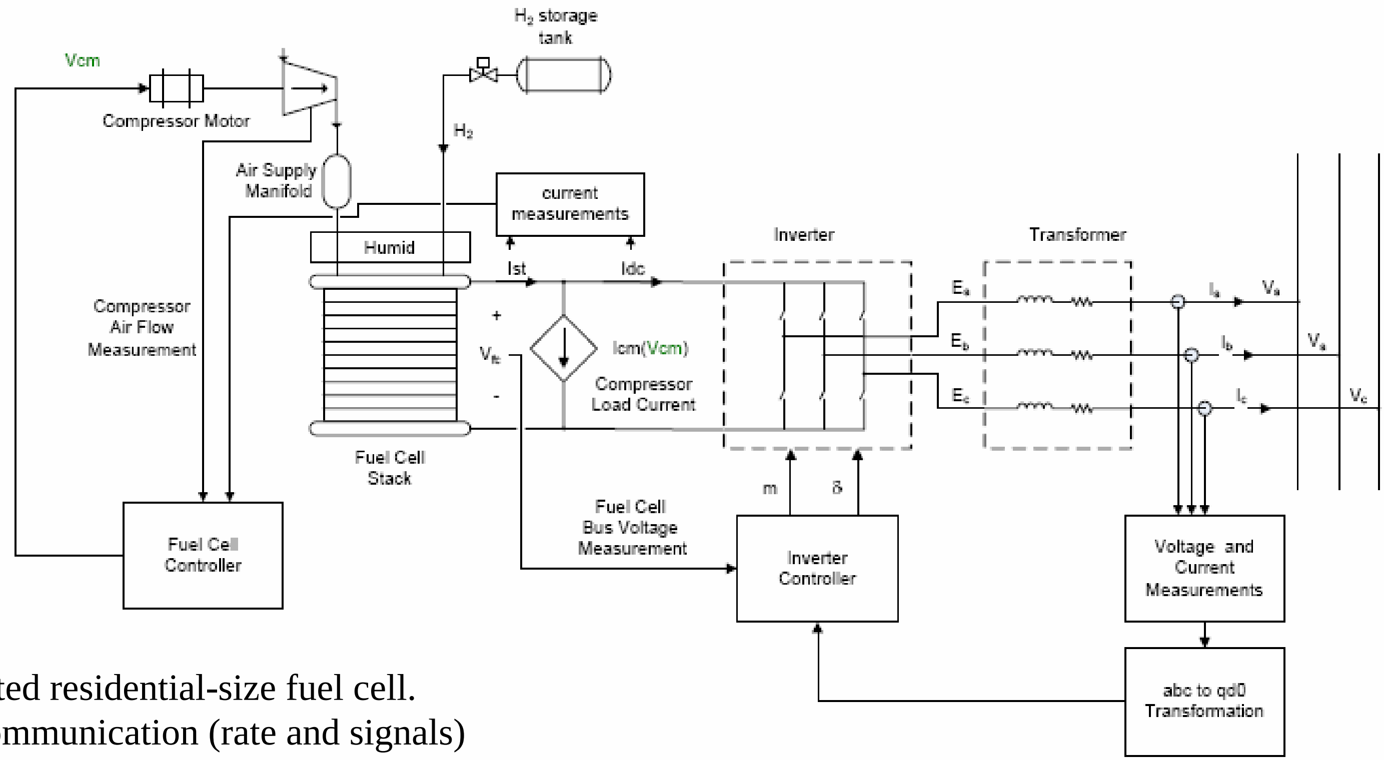


Communications and Control for Distributed Power Generation

- Define requirements for minimum communication and centralization among controllers embedded on alternative energy sources for a reliable distributed power grid

- Case study of load following and voltage regulation for a microgrid with multiple novel power sources

Example of the Control Strategies Developed at UM



Approach:

Consider a grid-connected residential-size fuel cell.

Define the minimum communication (rate and signals) among fuel cell controller, inverter controller, and substation.

Fast and reliable power response achieved by control design which accounts for constraints and system dynamics:

Oxygen Starvation for PEMFC

Over Temperature for SOFC or Fuel Processor

Goals:

Quantify the trade-off between oxygen starvation and load following (P/Q)

Establish requirements for fuel cell and battery system hybridization that

- mitigate the above tradeoff
- increase efficiency of residential power
- improve start-up
- allow re-configuration

Opportunities for development of new enabling technologies

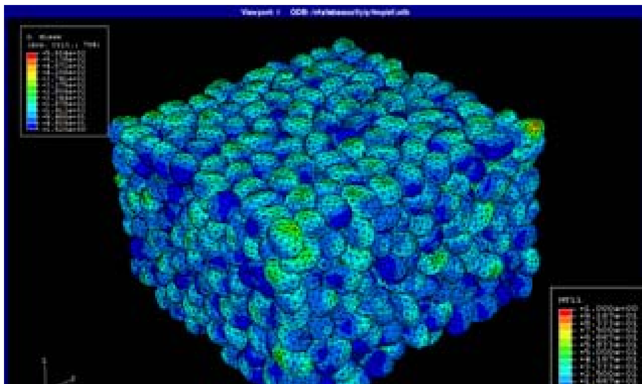
6.0 Power Electronics and Enabling Materials

"Basic science to explore opportunities for new materials…advances in nanotechnologies… development of nano-formed materials with enhanced energy storage capability…need to develop high density, high capacity battery energy storage based on novel materials and processes."

Five-Year Program Plan for FY2008 to FY2012 for Electric Transmission and Distribution Programs, August 2006, p. 46

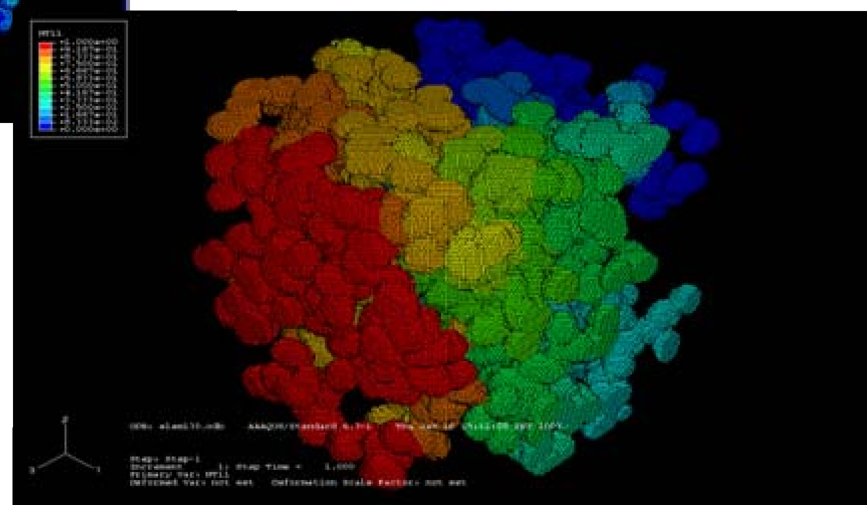
- UM Project to access and model nanotechnologies that dramatically improve Li-ion battery performance
- UM Project to define research agenda for developing novel materials for enhanced Li-ion battery

Examples of Nanotechnology activities at UM



Multiphysics simulations: mechanical, chemical and electrical engineering, electrochemistry involved.

Detailed examination of the effect of materials selection on battery performance

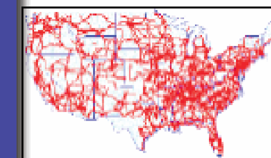


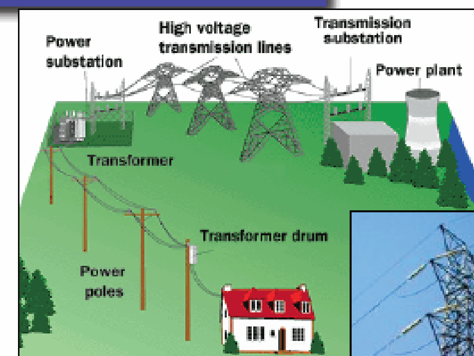
selection of materials design of packaging/form factor prediction of lifetime

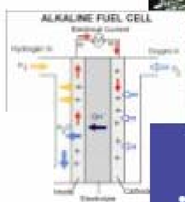
multiple scales
for energy research

power systems

• verified and validated models for sampling: Bayesian statistics
• models and tools for selection and integration
• verified and validated tools for prediction of environmental outcomes
• data management/model informatics: performance/control metrics







devices

• verified and validated models for design, performance and lifetime
• models and tools for selection and integration
• data management/model informatics: performance/control metrics

materials

• controllable, nanoscale architectures
• verified and validated models for properties and lifetime
• data management/model informatics: architectures and simulations

Fundamental research: gateway to innovation

Thomas Edison

Innovate: *"To start or introduce something new: be creative"* *-Webster*

Innovation means to make something new happen.

Henry Ford

Thank you!